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Source Assessment

Crushed Sandstone, Quartz, and Quartzite

State of the Art

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16. ABSTRACT

This report describes a study of atmospheric emissions from the crushed sandstone, quartz, and quartzite industry. Particulates are emitted from drilling, blasting, loading and unloading trucks, transport on unpaved roads, washing, crushing, screening, conveying, and stockpiling. The emission factor for respirable particulates from processing is 3.6 g/metric ton; washing, screening, crushing, and vehicular movement on unpaved roads contribute approximately 80% of the value. Free silica is the hazardous constituent of the emitted dust. Emission factors for carbon monoxide, nitrogen oxides, and fibers are 1.68 g/metric ton, 2.85 g/metric ton, and 1,360 fibers/metric ton, respectively. In order to evaluate the potential environmental effect of this industry, source severity was defined as the ratio of the maximum ground level concentration of an emission to be ambient air quality standard for criteria pollutants or to a modified TLV for noncriteria pollutants. The maximum source severity due to respirable free silica emission from a representative plant is 0.91. Air pollution control is not widely applied to emissions from crushed sandstone, quartz, and quartzite operations.

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State of the Art

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of air emissions from the crushed sandstone, quartz, and quartzite industry. This study was conducted to provide a better understanding of the distribution and characteristics of emissions from this industry. Further information on this subject may be obtained from the Extraction Technology Branch, Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act, and solid waste legislation. If control technology is unavailable, inadequate, or uneconomical, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include: process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number of operations (more than 500) in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries that represent sources of pollutants in accordance with EPA's responsibility, as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program, entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series. Reports prepared in this program are of two types: Source Assessment Documents, and State-of-the-Art Reports.

Source Assessment Documents contain data on pollutants from specific industries. Such data are gathered from the literature, government agencies, and cooperating companies. Sampling and analysis are also performed by the contractor when the available information does not adequately characterize the source pollutants. These documents contain all of the information necessary for IERL to decide whether a need exists to develop additional control technology for specific industries.

State-of-the-Art Reports include data on pollutants from specific industries which are also gathered from the literature, government agencies and cooperating companies. However, no extensive sampling is conducted by the contractor for such industries. Sources in this category are considered by EPA to be of insufficient priority to warrant complete assessment for control technology decisionmaking. Therefore, results from such studies are published as State-of-the-Art Reports for potential utility by the government, industry, and others having specific needs and interests.

This State-of-the-Art Report contains data on air emissions from the crushed sandstone, quartz, and quartzite industry. This project was initiated by the Chemical Processes Branch of the Industrial Processes Division at Research Triangle Park; Mr. D. K. Oestreich served as EPA Project Leader. The project was transferred to and completed by the Resource Extraction and Handling Division, IERL-Cincinnati, under Mr. John F. Martin.

ABSTRACT

This report describes a study of air pollutants emitted by the crushed sandstone, quartz, and quartzite industry. The potential environmental effect of this emission source was evaluated using source severity values. Source severity is defined as the ratio of the maximum ground level concentration of a pollutant at a representative plant boundary to a hazard factor. The hazard factor is the ambient air quality standard for criteria pollutants and an adjusted threshold limit value for other pollutants.

In 1972, 362 plants in the U.S. produced 24.3 x 10^6 metric tons of crushed sandstone, quartz, and quartzite. This accounted for 2.9% of the output of the aggregate industry (crushed limestone, granite, stone, sand, gravel, sandstone, quartz, and quartzite).

Atmospheric emissions of particulates occur from drilling, blasting, loading and unloading trucks, transport on unpaved roads, washing, crushing, screening, conveying, and stockpiling. The emission factor for respirable particulates from processing is 3.6 g/ metric ton, with washing, screening, crushing, and vehicular movement on unpaved roads contributing approximately 80% of the value. The hazardous constituent of the emitted dust is free silica. Emission factors for carbon monoxide, nitrogen oxides, and fibers are 1.68 g/metric ton, 2.85 g/metric ton, and 1,360 fibers/metric ton, respectively.

A representative crushed sandstone, quartz, and quartzite plant is defined as having a production rate of 454 metric tons/hr and emitting respirable particulates (less than 7 μm) and total particulates at the rate of 1.63 kg/hr and 15.7 kg/hr, respectively. The maximum source severity due to respirable free silica emissions from such a plant is 0.91.

Total particulates emitted from all crushed sandstone, quartz, and quartzite sources account for 0.005% of the national mass emissions burden of particulates. The mass of particulate emissions from such sources is expected to be 1.29 times greater in 1978 than it was in 1972.

Air pollution control is not widely applied to emissions from crushed sandstone, quartz, and quartzite operations.

This report was submitted in partial fulfillment of Contract No. 68-02-1874 by Monsanto Research Corporation under the sponsor of the U.S. Environmental Protection Agency. The study covers the period March 1975 to July 1977, and the work was completed in July 1977.

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ABBREVIATIONS AND SYMBOLS

a...d, f	-- variable exponents and coefficients used in numerous mathematical manipulations
A	-- cross-sectional area of falling granules
A_a	-- affected area where $\bar{\chi}/F>0.1$
ANFO	-- ammonium nitrate and fuel oil
A_{pfs}	-- affected population where $\bar{\chi}/F\geq 0.1$ for free silica particulates
b	-- width of the conveyor belt
BGD	-- background concentration of particulate
D_T	-- total dose of pollutant from a source
E	-- emission factor
E_{bCO}	-- emission factor for carbon monoxide from blasting
E_{bNO_x}	-- emission factor for nitrogen oxides from blasting
E_{br}	-- blasting respirable particulate emission factor
E_{bt}	-- blasting total particulate emission factor
E_{cr}	-- conveying respirable particulate emission factor
E_{crr}	-- crushing respirable particulate emission factor
E_{crt}	-- crushing total particulate emission factor
E_{ct}	-- conveying total particulate emission factor
E_d	-- drilling emission factor
E_{dr}	-- drilling respirable particular emission factor
E_{dt}	-- drilling total particulate emission factor
E_l	-- loading emission factor
E_{lr}	-- loading respirable particulate emission factor
E_{lt}	-- loading total particulate emission factor
E_{sr}	-- stockpile respirable particulate emission factor
E_{st}	-- stockpile total particulate emission factor
E_{tr}	-- transport respirable particulate emission factor
E_{tt}	-- transport total particulate emission factor

LIST OF ABBREVIATIONS AND SYMBOLS (continued)

E_u	-- unloading emission factor
E_{ur}	-- unloading respirable particulate emission factor
E_{ut}	-- unloading total particulate emission factor
E_{wsr}	-- washing and screening respirable particulate emission factor
E_{wst}	-- washing and screening total particulate emission factor
exp	-- natural log base e, 2.72
F	-- hazard factor
g	-- gravitational acceleration
GF	-- growth factor, 1982/1977 mass emissions
H	-- height of emission release
HC	-- hydrocarbons
H_f	-- height of fall
m	-- conveyor belt load
M	-- dispersion model designation
M_1	-- tan θ
M_2	-- ratio of yi/xi
mph	-- miles per hour
P	-- production rate of crushed sandstone, quartz, and guartzite
P.M.	-- particulate matter
Q	-- emission rate of a pollutant
Q_D	-- line source emissions rate
Q_T	-- total release of pollutants from a source
R	-- specific formation of airborne respirable dust
R/T	-- ratio of concentration of respirable to total particulates
S	-- severity
S'	-- stability class
$S_0 \ldots S_4$	-- high-volume sampler labels
SQQ	-- sandstone, quartz, and quartzite
TLV	-- threshold limit value
u	-- wind speed

U_b	-- linear speed of the conveyor belt
x, y, z	-- Cartesian coordinate points downwind of a source
x_c	-- crosswind distance from a line source
x_i, y_i	-- downwind distance Cartesian coordinate points
α	-- angle between downwind distance and line from source to sampler
Δ	-- difference between downwind and background concentration
θ	-- angle of mean wind direction
π	-- constant pi, 3.14
$\overline{\rho}_c$	-- material density of coal
σ_y	-- standard deviation of horizontal plume dispersion
σ_z	-- standard deviation of vertical plume dispersion
σ_{zI}	-- instantaneous standard deviation of vertical dispersion
χ	-- downwind concentration of a pollutant
$\overline{\chi}_{max}$	-- time-averaged maximum ground level concentration
Ψ	-- instantaneous dose concentration of a pollutant

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	to	Multiply by
Centimeter (cm)	Foot	3.281×10^{-2}
Centimeter^2 (cm^2)	Inch^2	1.550×10^{-1}
Centimeter^3 (cm^3)	Inch^3	6.102×10^{-2}
Degree Celsius (°C)	Degree Fahrenheit	$t_F^\circ = 1.8\ t_C^\circ + 32$
Kilogram (kg)	Pound-mass (lb mass avoirdupois)	2.204
Kilogram (kg)	Ton (short, 2,000 (lb mass)	1.102×10^{-3}
Kilometer^2 (km^2)	Mile^2	2.591
Meter (m)	Foot	3.281
Meter^2 (m^2)	Foot^2	1.076×10^{1}
Meter^3 (m^3)	Foot^3	3.531×10^{1}
Meter^3 (m^3)	Gallon (U.S. liquid)	2.642×10^{2}
Metric ton	Pound-mass	2.205×10^{3}
Radian (rad)	Degree (°)	5.730×10^{1}

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
Kilo	k	10^3	1 kg = 1 x 10^3 grams
Centi	c	10^{-2}	1 cm = 1 x 10^{-2} meter
Milli	m	10^{-3}	1 mm = 1 x 10^{-3} meter
Micro	μ	10^{-6}	1 μm = 1 x 10^{-6} meter

[a] Metric Practice Guide. ASTM Designation E 380-74, American Society for Testing and Materials, Philadelphia, Pennsylvania, November 1974. 34 pp.

SECTION 1

INTRODUCTION

The conversion of naturally occurring sandstone, quartz, or quartzite (SQQ) rocks into a crushed form involves mining from open quarries and processing at finishing plants. Air pollution emissions are created by the quarrying and processing activities.

An investigation of crushed sandstone, quartz, and quartzite operations was conducted to provide a better understanding of the distribution and characteristics of emissions from the data available in the literature and limited sampling, and to ascertain the need for developing control technology in the industry.

This document contains information on the following items:

- A method to estimate the emissions from crushed sandstone, quartz, and quartzite processing.
- Composition of emissions.
- Hazard potential of emissions.
- Geographical distribution and source severity.
- Trends in the crushed sandstone, quartz, and quartzite industry and their effects on emissions.
- Type of control technology used and proposed.

SECTION 2

SUMMARY

The crushed sandstone, quartz, and quartzite industry converts naturally occurring sandstone, quartz, and quartzite rock deposits into a crushed form for use predominantly (83% of the output) in the construction industry. There are 362 plants in the United States which produced 24.3 x 10^6 metric tons[a] of crushed sandstone, quartz, and quartzite in 1972, accounting for 2.9% of the output of the aggregate industry (crushed limestone, granite, stone, sand, gravel, sandstone, quartz, and quartzite). Contingency forecasts of crushed sandstone, quartz, and quartzite demands in the year 2000 have been reported to be 83.6 x 10^6 metric tons to 106.0 x 10^6 metric tons.

Atmospheric emissions of particulates occur from several unit operations; drilling, blasting, loading and unloading trucks, transport on unpaved roads, washing, crushing, screening, conveying, and stockpiling. Although an estimate of the emission factor is available in the published literature as 5,650 grams of suspended particulate per metric ton of processed material, this number has not been validated by on-site sampling. Field sampling of emissions was therefore conducted. The emission factor for respirable particulates from crushed sandstone, quartz, and quartzite processing is 3.6 g/metric ton, with washing, screening, crushing, and vehicular movement on unpaved roads (between quarry and plant, and pit and plant) contributing about 80% of the value. The hazardous constituent of the emitted dust is free silica (17 wt % average), prolonged exposure to which may result in the development of a pulmonary fibrosis known as silicosis. Particulate emission factors and the mass of total and respirable particulates emitted from SQQ unit operations are presented in Table 1. Emission factors for carbon monoxide, nitrous oxides, and fibers are 1.68 g/metric ton, 2.85 g/metric ton, and 1,360 fibers/metric ton, respectively.

A representative crushed sandstone, quartz, and quartzite plant was defined by a production rate of 454 metric tons/hr; it emits dust at the rate of 1.63 kg/hr respirable particulates (less than

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[a] 1 metric ton equals 10^6 grams; conversion factors and metric system prefixes are presented in the prefatory material.

TABLE 1. EMISSION FACTORS AND MASS EMISSION LEVELS FROM SANDSTONE, QUARTZ, AND QUARTIZE SOURCES

Unit operation	Particulate emission factor, g/metric ton		Particulate mass emissions, metric ton/yr		Percent of total	
	Respirable	Total	Respirable	Total	Respirable	Total
Drilling	0.009	0.05	0.2	1.2	0.24	0.15
Blasting	0.003	0.56	0.07	13.6	0.08	1.65
Loading	0.0006	0.012	0.01	0.3	0.01	0.04
Unloading	0.05	0.13	1.2	3.1	1.41	0.4
Washing and screening	0.84	7.6	20.4	184.7	24	22.37
Crushing	1.34	13.4	32.6	325.6	38.41	39.44
Conveying	0.11	1.73	2.7	42.0	3.2	5.1
Transport on unpaved roads	0.74	4.1	6.8	99.6	21.21	12.1
Stockpiles	0.4	6.4	9.7	155.5	11.43	18.83
TOTAL	3.6	34.7	84.88	825.6	100[a]	100[a]

[a]May not add to 100% due to rounding.

7 μm) and 15.7 kg/hr total particulates. The source severity value is the ratio of the maximum ground level concentration (calculated from the emission rate) at the representative plant boundary to the pollutant hazard factor. The hazard factor, F, is defined as the EPA primary air quality standard. When EPA criteria do not exist, an adjusted threshold limit value (TLV®) is used which allows for exposure time and general population sensitivity. The maximum source severity due to respirable free silica emissions from such a plant is 0.91. The population exposed to an average ground level concentration ($\overline{\chi}$) of free silica from a representative plant for which $\overline{\chi}/F$ greater than 0.1 was estimated to be five persons.

Total particulates emitted from all SQQ sources account for 0.005% of the national mass emissions burden of particulates. In Arkansas, 0.13% of the total particulates emitted are from SQQ sources. Every other state has a lower SQQ emissions burden. The mass of particulate emissions from SQQ sources is expected to be 1.29 times greater in 1978 than it was in 1972 (based upon a projected 4.3% annual growth rate for SQQ production).

Air pollution control is not widely applied to emissions from crushed sandstone, quartz, and quartzite operations. Since the quantity of dust emitted from these operations is dependent on the dryness of material handled, any method used to add moisture is helpful in controlling dust levels.

SECTION 3

SOURCE DESCRIPTION

PROCESS DESCRIPTION

Emission Sources

The conversion of naturally occurring sandstone, quartz, or quartzite deposits into a crushed form involves a series of physical operations similar to those used in the crushed granite and crushed stone industries as shown schematically in Figure 1. The deposits are first loosened by drilling and blasting, then washed, loaded, and transported to the processing plant by trucks or belt conveyors. Processing includes such operations as crushing, pulverizing, screening, and conveying. After processing, the crushed material is loaded for transport to customers or to stockpiles for storage.

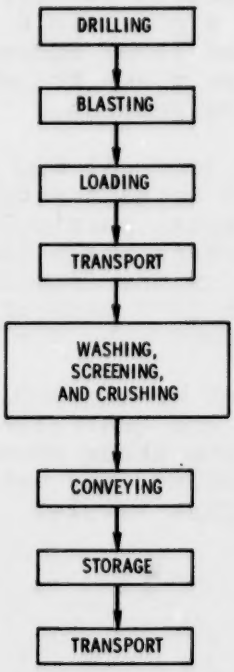

Figure 1. Flow of crushed sandstone, quartz, and quartzite operations.

Respirable particulate (less than 7 μm) emission sources in the crushed sandstone, quartz, and quartzite industry can be divided into two categories: 1) sources associated with actual processing such as crushing, screening, and conveying operations; and 2) fugitive dust sources such as stockpiles and vehicle traffic on unpaved roads. Quarrying operations such as drilling, blasting, and transfer operations are also fugitive dust sources.

Source Composition

Sandstone is a detrital sedimentary rock formed by the cementation of individual grains of sand-size particles, 62 μm to 2 mm in diameter. The grains in most sands are commonly composed of mineral quartz, but many other minerals and rock fragments such as feldspar, clay minerals, garnet, zircon, rutile, magnetite, pyrite, chromite, etc., may also be present in small quantities (1).

Quartzites are mostly formed by the metamorphism of sandstone; however, some are also formed by metasomatic introduction of quartz and other elements such as metals and sulfur (2).

Quartz is the most abundant and widespread of all minerals. It has the chemical composition SiO_2 (silicon dioxide) and is the principal constituent of sandstone, of quartzite, and of unconsolidated sand and gravel (2).

Sandstone, quartz, and quartzite are combined into one category by the Bureau of Mines because of the similar end use of products. This definition was adopted to facilitate data gathering in this assessment.

FACTORS AFFECTING EMISSIONS

Calculation of the source severity and the state and national emissions burdens, necessitates a knowledge of the emission rate for every source in the country. Conducting emission measurements on a source-by-source basis was impractical due to the large number of individual sources and the diversity of source types. A method was therefore developed to derive an emission factor as grams of particulates emitted per metric ton of crushed sandstone, quartz, or quartzite processed.

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(1) McGraw-Hill Encyclopedia of Science and Technology, Volume 12. McGraw-Hill Book Company, Inc., New York, New York, 1960. pp. 23-25.

(2) McGraw-Hill Encyclopedia of Science and Technology, Volume 11. McGraw-Hill Book Company, Inc., New York, New York, 1960. pp. 180-183.

The emission rate for each of the unit operations is estimated as the product of the emission factor and the crushed sandstone, quartz, and quartzite production rate. This relationship can be stated simply as shown in Equation 1.

$$Q = E \times P \qquad (1)$$

where Q = emission rate of particulates, g/hr
E = emission factor in g/metric ton of crushed sandstone, quartz, or quartzite processed
P = production rate of crushed sandstone, quartz, or quartzite, metric tons/hr

The overall emissions from crushed sandstone, quartz, or quartzite operations are due to drilling, blasting, loading, vehicular movement on unpaved roads (between quarry and pit, and pit and plant), crushing, conveying, screening, and stockpiling. Emissions from all of these unit operations (except blasting) are influenced by particle size distribution, rate of handling, moisture content of the handled material, and type of equipment used.

A detailed literature survey was conducted to obtain published data on the extent to which various factors influence the overall emissions and on the relative contributions of the unit operations to overall emissions. Although estimates of emission factors for some unit operations are available in the published literature, no studies were conducted or reported to validate the estimated emission factors (Appendix A).

A limited sampling of emissions from a crushed quartzite plant was therefore conducted. (See Appendix B for details and results of the sampling.) The results of the sampling and the literature study indicate that respirable free silica particulates are of concern. Crushing, washing, screening, and transport on unpaved roads account for over 80% of the respirable particulates emitted from SQQ operations.

The factors influencing emissions from vehicular movement on unpaved roads are vehicle speed, vehicle weight and cross-sectional area, number of wheels, tire width, particle size distribution, and moisture content of unpaved road surface material. Though considerable literature is available on the magnitude of unpaved road emissions, little has been done to correlate the emissions with soil or vehicle characteristics.

GEOGRAPHICAL DISTRIBUTION

There were 362 crushed sandstone, quartz, and quartzite quarries in the U.S. with a total output of 24.3×10^6 metric tons in 1972. Arkansas ranked first in output with 5.2×10^6 metric tons in 1972, followed by California, Pennsylvania, Wisconsin,

Texas, West Virginia, South Dakota, and Ohio. Together, these 8 states accounted for 73% of the total crushed sandstone, quartz, and quartzite production in the United States (3). Table 2 and Figure 2 present the crushed sandstone, quartz, and quartzite output in 22 states in the United States.

TABLE 2. CRUSHED SANDSTONE, QUARTZ, AND QUARTZITE SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1972, BY STATE AND RESPECTIVE POPULATION DENSITY

State	Amount of sandstone, quartz, and quartzite sold or used (4), 10^3 metric tons	Population density, persons/km^2
Alabama	52	27
Arizona	505	7
Arkansas	5,180	15
California	4,828	50
Colorado	195	7
Georgia	75	31
Missouri	201	27
Montana	352	2
New Mexico	100	3
New York	648	145
North Carolina	58	39
Ohio	836	102
Oregon	168	9
Pennsylvania	3,263	103
South Dakota	854	3
Texas	960	17
Utah	137	5
Vermont	46	19
Virginia	668	46
Washington	811	20
West Virginia	920	29
Wisconsin	1,038	31
Other states[a]	2,476	Not determined
TOTAL[b]	24,344	

[a] Includes Connecticut, Idaho, Kansas, Kentucky, Maryland, Michigan, Minnesota, Nevada, New Hampshire, Oklahoma, Tennessee, and Wyoming.

[b] Data may not add to totals shown because of independent rounding.

(3) Mineral Industry Surveys. U.S. Department of the Interior, Washington, D.C., 1972. 12 pp.

(4) Drake, H. J. Stone. In: Minerals Yearbook, 1972, Volume I. U.S. Department of the Interior, Washington, D.C., 1974. 1172 pp.

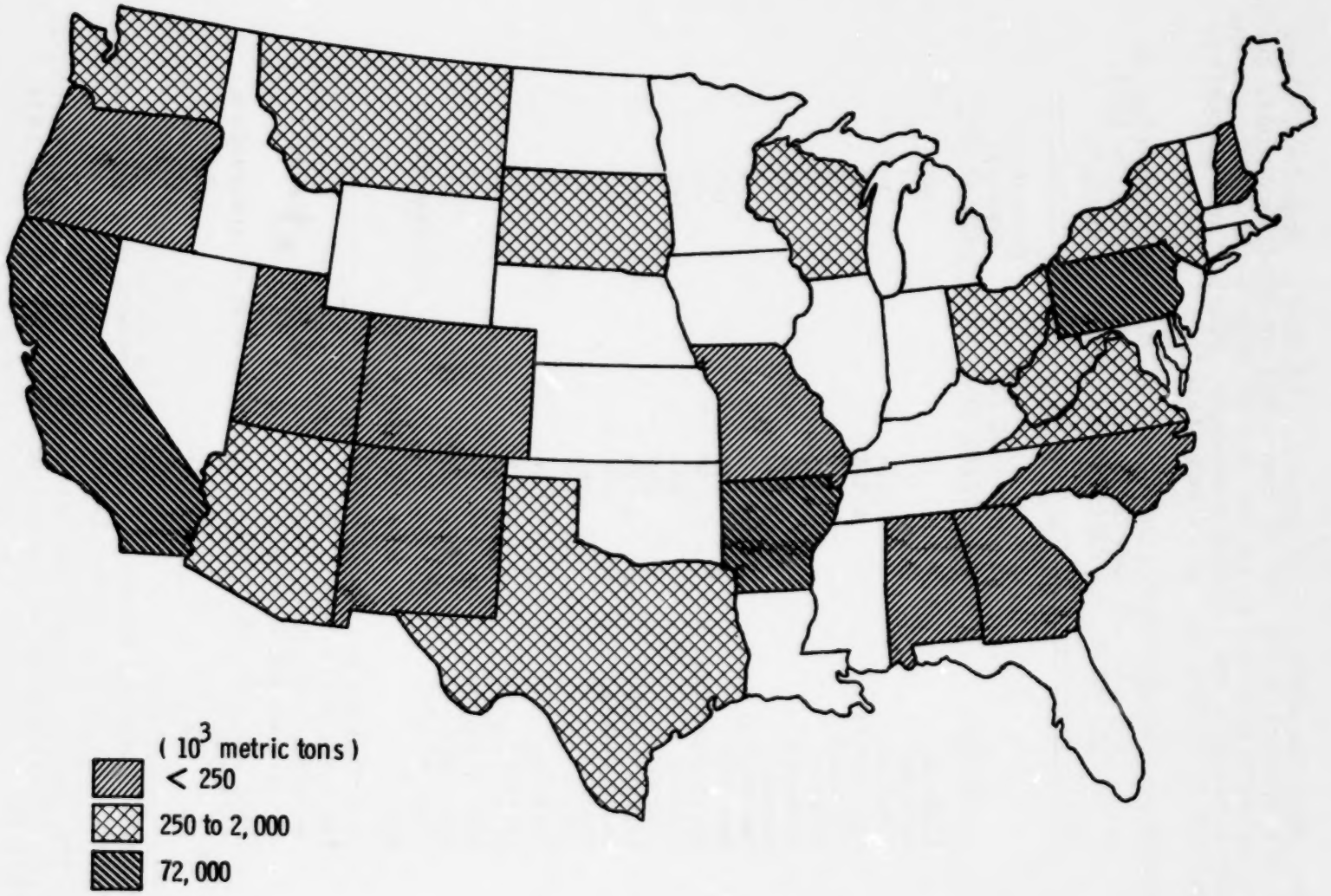

Figure 2. Distribution of sandstone, quartz, and quartzite production.

SECTION 4

EMISSIONS

SELECTED POLLUTANTS

The major pollutants emitted from crushed sandstone, quartz, and quartzite processing are particulates containing free silica. The prolonged inhalation of these dusts may result in the development of a disabling pulmonary fibrosis known as silicosis. The action of silica on the lungs results in the production of a diffuse, nodular fibrosis which is progressive and may continue to increase for several years after exposure is terminated. The first and most common symptoms of uncomplicated silicosis are shortness of breath on exertion and dry cough. When the disease advances, the shortness of breath becomes worse and the cough more troublesome. Further progress of the disease results in marked fatigue, loss of appetite, pleuritic pain, and total incapacity to work. Extreme cases may eventually cause death due to destruction of the lung tissues (5).

The American Conference of Governmental Industrial Hygienists has suggested a TLV (in mg/m^3) of 10/(% Quartz + 2) for respirable dusts containing quartz or free silica. Dusts with less than or equal to 1% silica are termed "inert," and a TLV of 10 mg/m^3 is suggested for these (6). Each trace element investigated possesses a TLV documenting the hazardous nature of the pollutant from a health or nuisance standpoint. Emissions of carbon monoxide and nitrogen oxide from blasting are air criteria pollutants which also possess suggested TLV's. Fibers are also emitted from SQQ operations; they are associated with many forms of fibrosis similar to silicosis.

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(5) Sax, N. I. Dangerous Properties of Industrial Materials, Third Edition. Reinhold Book Corporation, New York, New York, 1968. pp. 1088-1089.

(6) TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1976. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1976. p. 32.

CHARACTERISTICS

Mass Emissions

Emission factors for pollutants from crushed sandstone, quartz, and quartzite plants were derived from literature and sampling data (as detailed in Appendix B) and are presented in Table 3. Mass emission quantities of these pollutants based on production levels are presented in Table 4 along with the percent of emissions attributed to each operation.

The emission of total particulates from SQQ sources accounts for 0.005% of the national mass emission of total particulates and 0.13% of the mass emissions of total particulates in Arkansas. Carbon monoxide and nitrogen oxide emissions account for less than or equal to 0.009% of any state mass level and less than 0.001% of the national emission level of each pollutant.

Composition of Emissions

An analysis of the emissions from crushed sandstone, quartz, and quartzite emissions (Appendix B) shows that free silica, constituting about 17% by weight, is the only hazardous component. Remaining constituents are inert. An elemental analysis of the particulate was also conducted (Appendix B, Table B-6), and the average percentages were applied to the emission Factors for respirable particulates to determine trace element emission factors.

DEFINITION OF A REPRESENTATIVE SOURCE

Consultations with industry experts showed that crushed SQQ plants have an average production rate of approximately 454 metric tons/hr (personal communication with Fredrick A. Renninger, National Crushed Stone Association, Washington, D.C., 7 November 1975).

The mean emission factor was determined by sampling a crushed quartzite plant with operating parameters similar to those of the representative plant (Appendix B). Thus, the representative source emits dust at a rate of 1.63 kg/hr respirable particulates and 15.7 kg/hr total particulates.

The representative population density is taken as a production-weighted population density and is equal to 38.8 persons/km^2. The percentage of SQQ sold or used by producers in each state was utilized to weight the population density in each state (Table 2). The resulting average population density of 38.8 persons/km^2 is used as representative of the source. The representative distance from the plant is defined using the major contributing source within the plant as a reference point. The distance of the plant boundaries from this reference point is

TABLE 3. EMISSION FACTORS FROM CRUSHED SANDSTONE, QUARTZ, AND QUARTZITE OPERATIONS (g/metric ton)

Unit operation	Emission factors					
	Respirable particulates	Total particulates	Respirable free silica particulates	Carbon monoxide	Nitrogen oxides	Fibers
Prilling	0.009	0.05	0.002	[a]	[a]	[b]
Blasting	0.003	0.56	0.0005	1.68	2.85	[b]
Loading	0.0006	0.012	0.0001	[a]	[a]	[b]
Unloading	0.05	0.13	0.008	[a]	[a]	[b]
Transport on unpaved roads	0.74	4.1	0.03	[a]	[a]	[b]
Washing and screening	0.84	7.6	0.14	[a]	[a]	[b]
Crushing	1.34	13.4	0.23	[a]	[a]	1,360
Conveying	0.11	1.73	0.02	[a]	[a]	[b]
Stockpiles	0.4	6.4	0.06	[a]	[a]	[b]
TOTAL	3.6	34.7	0.61	1.68	2.85	1,360[c]

[a] Not emitted. [b] Not sampled and/or no literature available. [c] Fibers/metric ton.

TABLE 4. MASS EMISSION LEVELS OF CRITERIA POLLUTANTS FROM CRUSHED SANDSTONE, QUARTZ, AND QUARTZITE OPERATIONS (metric tons/yr)

Unit operation	Mass emissions					
	Total particulates	Percent of total	Carbon monoxide	Percent of total	Nitrogen oxide	Percent of total
Drilling	1.2	10.15	[a]	[a]	[a]	[a]
Blasting	13.6	1.65	40.8	100	69.2	100
Loading	0.3	0.04	[a]	[a]	[a]	[a]
Unloading	3.1	0.4	[a]	[a]	[a]	[a]
Washing and screening	184.7	22.37	[a]	[a]	[a]	[a]
Crushing	325.6	39.44	[a]	[a]	[a]	[a]
Conveying	42.0	5.1	[a]	[a]	[a]	[a]
Transport on unpaved roads	99.6	12.1	[a]	[a]	[a]	[a]
Stockpiles	155.5	18.83	[a]	[a]	[a]	[a]
TOTAL	825.6	100[b]	40.8	100	69.2	100

[a] Not emitted. [b] May not add to 100% due to rounding.

taken as the radius of a circle whose area is equal to the area of the representative plant. By assuming crushed SQQ plants have the same average area as crushed stone plants (0.53 km^2), the representative distance to the plant boundary is 410 m (7).

A representative SQQ plant growing at the same rate as the industry is expected to have an annual growth rate of 4.3%. Similarly, the mass emission level of particulates from the representative plant in 1982 is expected to be 1.23 times greater than the 1977 level.

SOURCE SEVERITY AND AFFECTED POPULATION

The source severity, used to indicate the hazard potential of a representative emission source, is the ratio of the time-averaged maximum ground level concentration ($\overline{\chi}_{max}$) to a hazard factor (F). In order to calculate severity, S (which equals $\overline{\chi}_{max}/F$) (8), a mathematical model describing the dispersion of pollutants in the atmosphere is employed. For open sources, the model employs the time-averaged concentration of a pollutant occurring at a single point at ground level at the plant boundary. This concentration may occur only once a year and be considered a worst case concentration. The hazard factor is derived from ambient air quality criteria or reduced threshold limit values.

Ground Level Concentration

The minimum distance from the major contributing emission source to the representative crushed SQQ plant boundary has been determined to be 410 m. This is the minimum distance at which public exposure to the pollutant could occur. The following formula in conjunction with class C meteorological conditions (approximate U.S. average) was used to calculate the maximum ground level, instantaneous concentration, χ_{max} (9):

$$\chi_{max} = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad (2)$$

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(7) Blackwood, T. R., P. K. Chalekode, and R. A. Wachter. Source Assessment: Crushed Stone. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio. July 1977. 91 pp.

(8) Eimutis, E. C., B. J. Holmes, and L. B. Mote. Source Assessment: Severity of Stationary Air Pollution Sources - A Simulation Approach. EPA-600/z-76-032e, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 1976. 133 pp.

(9) Turner, D. B. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970. 84 pp.

where Q = mass emission rate
$\sigma_y = 0.209\ x^{0.903}$
$\sigma_z = 0.113\ x^{0.911}$
u = 4.5 m/s (approximate U.S. average wind speed)
x = 410 m
$\pi = 3.14$

The instantaneous ground level concentration of respirable free silica particulates at 410 m (using the emission rate determined for Equation C-7) is thus 3.4 $\mu g/m^3$. This must be corrected to the time-averaged maximum, $\bar{\chi}_{max}$, for 24 hr as described by Nonhebel (10), so that the mean concentration becomes 1.9 $\mu g/m^3$. This means that the maximum ground level concentration at the boundary of the representative plant during a 24-hr period is 1.9 $\mu g/m^3$ above background levels (worst case).

Hazard Factor

Since no ambient air quality criteria exist for compounds such as free silica, the hazard factor, F, is thus a reduced threshold limit value and is defined as follows:

$$F = \frac{8}{24} \times \frac{1}{100} \times TLV \qquad (3)$$

The derivation of F utilizes the TLV corrected from 8-hr to 24-hr exposure, with a safety factor of 100 applied to the calculation. The free silica hazard factor for the purposes of this report is calculated as 1.77 $\mu g/m^3$ (Appendix C), comparable to the hazard factor for respirable emissions since the TLV is for respirable emissions. For total particulates, F shall be defined as the 24-hr ambient air quality standard of 260 $\mu g/m^3$.

Source Severity

For the representative crushed SQQ plant, the maximum severity is determined from the ratio of the time-averaged maximum ground level concentration of the emission species to the hazard factor for the species ($\bar{\chi}_{max}/F$). Pollutant severity equations utilized and source severities for respirable and free silica particulates are calculated in Appendix C. The source severities per unit operation are presented in Table 5.

Emissions of nitrogen oxides and carbon monoxide from blasting possess severities of 0.09 and 0.0002, respectively. The severity for fibers from crushing operations is 2.2×10^{-7}. Trace element emissions possess a range of severities (Table C-3, Appendix C) from 0.00001 to 0.04 (lead), based on sampling of

(10) Nonhebel, G. Recommendations on Heights for New Industrial Chimneys. Journal of the Institute of Fuel, 33:479, 1960.

TABLE 5. POLLUTANT SOURCE SEVERITIES PER UNIT OPERATION

Unit operation	Pollutant	
	Respirable particulates	Free silica particulates
Drilling	0.00005	0.001
Blasting	0.00003	0.0007
Loading	0.00001	0.0002
Unloading	0.0005	0.1
Washing and screening	0.008	0.2
Crushing	0.013	0.34
Conveying	0.001	0.03
Transport on unpaved roads	0.007	0.19
Stockpiles	0.0003	0.008
TOTAL	0.034	0.91

the crusher operation, which had the highest respirable particulate severity (Table 5). Based on these low severities, further investigation of these pollutants is not warranted.

Affected Population

The affected population refers to the number of persons potentially exposed to a time-averaged ground level concentration of a pollutant, χ, for which χ/F is greater than 0.1. The affected population was calculated for free silica since this is the only pollutant species which has a source severity greater than 0.1. The population potentially exposed to this level is five persons (Appendix C).

SECTION 5

CONTROL TECHNOLOGY

STATE OF THE ART

Air pollution control technology is not widely applied to emissions from crushed sandstone, quartz, and quartzite operations. The quantity of dust generated from the various operations is dependent upon the dryness of the handled material; hence, any method used to add moisture is helpful in controlling dust levels. Natural phenomena such as rain or snow and in-process washing or spraying operations inhibit dust emissions as the dust adhering to water is less prone to be emitted.

FUTURE CONSIDERATIONS

The fugitive and point sources of dust in the processing of sandstone, quartz, and quartzite are drilling, blasting, loading, unpaved road transport, crushing, screening, conveying, and stockpiling.

Dust emissions from dry percussion drilling operations can be controlled by adding water or water mixed with a surfactant into the air used for flushing the drill cuttings from the hole. Dilution ratios range from 800 to 3,000 parts of water to 1 part surfactant. The proper amount of solution, about 0.026 m^3/hr for an 89-mm diameter hole, causes the drill cutting to be blown from the hole as damp, dust-free pellets (11).

In conventional mining of coal, water-filled plastic bags with or without solid stemming material (clay) are used for stemming dust emissions from blast holes. This method reduces dust concentrations by 20% to 80% and explosive consumption by about 10% (12). Instead of liquids, pastes with a cellulose or bentonite base can be used if they have "thixotropic" properties; i.e., they are gelatinous in repose but become liquid when vibrated. A similar control method may be applicable for reducing particulate emissions from blasting in sandstone, quartz, and quartzite mining.

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(11) Jones, H. R. Fine Dust and Particulates Removal. Noyes Data Corporation, Park Ridge, New Jersey, 1972. 307 pp.

(12) Grossmueck, G. Dust Control in Open Pit Mining and Quarrying. Air Engineering, 10(25):21, 1968.

Release of carbon monoxide, nitrogen oxides, and other gases such as aldehydes and hydrogen can be curtailed by having a dry blast hole and by carrying out the detonation properly to prevent incomplete combustion.

Loading of the blasted sandstone, quartz, and quartzite into trucks by front-end loaders results in dust emissions. Wetting of the broken stone with water or water mixed with a surfactant will alleviate the dust emissions. Emissions due to wind erosion during transport can be reduced by covering the load with a tarpaulin or wetting its surface with water or water mixed with chemicals.

Water application is also an effective method for controlling emissions from unpaved roads; however, approximately 5% to 8% moisture (by weight) must be applied to suppress the dust emissions (13). Additives such as calcium chloride can be used to reduce the surface tension of water so that the dust can be wetted with less water. Calcium chloride can be applied at a cost of approximately $\$0.15/m^2$ treated per year (14). The major problem involved in its use is the corrosion of vehicle bodies and leaching by rainwater or melting snow. More frequent applications may be necessary during summer months.

Another effective method of dust control is to mix stabilizing chemicals into the road surface to a depth of approximately 20 mm to 50 mm (15). One cement company uses a special emulsion agent[a] and a treatment which involves spraying a solution of 4 parts of water and 1 part of the emulsion agent at the rate of $0.0091\ m^3/m^2$ of the road surface. Certain pretreatment measures such as working the road surface into a stiff mud are necessary to prevent the binder in this emulsion agent from sticking to the vehicles. Periodic maintenance using a 1:7 emulsion agent/water solution spray keeps the emulsion agent binder active. This dust control program was found to give 3 years of service at a total cost of $\$0.12/m^2$.

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[a]Coheren, supplied by Golden Bears Division, Witco Chemicals Co.

(13) Dust Suppression. Rock Products, 75:137, May 1972.

(14) Vandegrift, A. E., L. J. Shannon, P. G. Gorman, E. W. Lawless, E. E. Sallee, and M. Reichel. Particulate Pollutant Systems Study, Volume III: Handbook of Emission Properties. Contract CPA-22-69-104, U.S. Environmental Protection Agency, Durham, North Carolina, May 1971. 607 pp.

(15) Significant Operating Benefits Reported from Cement Quarry Dust Control Programs. Pit and Quarry, 63(7):116, 1971.

In some counties in Iowa, mixing cutback asphalt into the road surface to a depth of 5 cm to 8 cm has been investigated (16). This type of surface treatment reduces dust emissions, but it requires periodic maintenance such as patching of the potholes.

Treating the road surface with oil once a month is another efficient method of controlling unpaved road dust emissions. The cost for such applications is estimated to be $\$0.10/m^2$ treated per year (11). However, a study conducted in New Jersey shows that 70% to 75% of the oil applied moves from the surface of the road by dust transport and runoff, and thus the oil or its heavy metal constituents such as lead may cause ecological harm (17). Furthermore, surface oiling requires regular maintenance because roads treated in this manner develop potholes.

Lignin sulfonates, byproducts from paper manufacture, are also used to control dust emissions. A commercially available lignin sulfonate[a] was tested on a farm access road in Arizona State University (18). The method proved quite successful, giving 5 years of service and effective dust suppression at a cost of $\$0.47/m^2$ for 5 years ($\$0.10/m^2$-yr).

Paving the road surface is the best method for controlling dusts, but it is impractical due to the high cost involved and the temporary nature of crushed sandstone, quartz, and quartzite plants.

The simplest and least expensive means of controlling dust from crushing, screening, conveying, and stockpiling is through the use of wetting agents and sprays at critical points. A crushed rock production plant uses a dust suppression system[b] and a chemical wetting agent. Approximately 0.004 m^3 of the concentrated wetting agent is diluted 1,000 times by volume with water using an automatic proportioner. The solution is sprayed at the top and bottom of cone crushers at the rate of 0.0042 m^3 of solution per metric ton of material being crushed. This system also

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[a]Orzan A, supplied by Crown Zellerbach Corporation.

[b]Chem-Jet, supplied by Johnson-March Corporation.

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(16) Hoover, J. M. Surface Improvement and Dust Palliation of Unpaved Secondary Roads and Streets. ERI Project 856-S, Iowa State Highway Commission, Des Moines, Iowa, July 1973. 97 pp.

(17) Freestone, F. J. Runoff of Oils from Rural Roads Treated to Suppress Dust. EPA R2-72-054, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1972. 29 pp.

(18) Bub, R. E. Air Pollution Alleviation by Suppression of Road Dust. M.S.E. thesis, Arizona State University, Tempe, Arizona, June 1968. 45 pp.

helps in reducing dust emissions at transfer points, screening operations, storage bins, and stockpiling operations (19).

Such a system has many cost-saving advantages. It requires no ducts, hooding, or other enclosures for crushers, screens, or conveyors. The equipment is in the open and allows the operators to see the entire material flow in open areas. The dust is not collected and there is no solid waste disposal or water pollution problem.

In a crushed stone plant (with processes similar to those of a crushed sandstone, quartz, and quartzite plant), a baghouse is used to control dust emissions from cone crushers, scalping screens, and twin sizing screens, and at the shuttle and transfer conveyors. The range of dust collected is 2,722 kg to 5,443 kg in a 10-hr day from a 182-metric ton/hr plant (20). A baghouse does not provide for dust control in stockpile areas unless these areas are totally enclosed.

The dust collected in the baghouse presents a solid waste problem. The alternative disposal methods are to put the dust into settling basins or to develop sales opportunities. Depending on the type of material and the local market conditions, such uses may include manufactured sand, underslab fill, and asphalt filler (21).

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(19) Harger, H. L. Methods Used by Transit Mix Operators to Meet Air Pollution Control District Requirements. National Sand and Gravel Association and National Ready Mixed Concrete Association, Washington, D.C., April 1971. 22 pp.

(20) Trauffer, W. E. Maine's New Dust-Free Crushed Stone Plant. Pit and Quarry, 63(2):96, 1970.

(21) Ozol, M. A., S. R. Lockete, J. Gray, R. E. Jackson, and A. Preis. Study to Determine the Feasibility of an Experiment to Transfer Technology to the Crushed Stone Industry. Contract NSF-C826, National Science Foundation, June 1974. 50 pp.

SECTION 6

GROWTH AND NATURE OF THE INDUSTRY

PRESENT TECHNOLOGY

Present technological improvements include the use of larger and more efficient crushing and screening plants. Primary crushing is often done near the pit, usually using jaw or gyratory crush ers. Secondary crushing is done by cone crushers or gyratories. For screening, horizontal screens are generally used. Storage of finished crushed sandstone, quartz, and quartzite is done in open areas.

In refractory plants, rotary washers or water tables are used to remove impurities such as clay, and ball mills or rod mills are used for grinding.

PRODUCTION TRENDS AND GROWTH FACTOR

Production of crushed sandstone, quartz, and quartzite is tied closely to activity in the product consuming industries. Since the construction industry consumes more than 83% of the output, the production of crushed sandstone, quartz, and quartzite is associated chiefly with the needs of this industry (3). The annual growth rate is assumed is equivalent to that of the sand and gravel industry, 3.9% to 4.7% (22), with an average of 4.3% per year. The forecast for crushed sandstone, quartz, and quartz-ite demand until the year 2000 is presented in Table 6.

Transportation costs constitute a major part of the delivered cost of crushed sandstone, quartz, and quartzite. In many cases, these costs may exceed the sales value of the material at the processing plant. Hence, such plants are located near the point of use. However, local zoning and environmental regulations and depletion of urban deposits may necessitate the location of future plants away from the point of use. This should increase

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(22) Ochsner, J. C., P. K. Chalekode, and T. R. Blackwood. Source Assessment: Transport of Sand and Gravel. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio. (Final document submitted to the EPA by Monsanto Research Corporation, October 1977.) 63 pp.

TABLE 6. GROWTH RATE OF CRUSHED SANDSTONE, QUARTZ, AND QUARTZITE PRODUCTION

Year,	Production, 10^3 metric tons
1972	24,344
1977	30,049
1982	37,090
1990	51,941
1995	64,110
2000	79,131

the use of rail and barge systems in order to hold down transportation costs. Truck haulage will still remain important, especially for local delivery of crushed product, even if rail and water transportation are used for long hauls to central distribution points. This finally may result in an increase in the delivered price of crushed sandstone, quartz, and quartzite.

A growth factor for SQQ source emissions is computed from the ratios of mass emission levels in 5 years to the present level. Based on the data presented in Table 6, the growth factor for total particulate emissions from the period 1972 to 1978 is 1.23.

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13. Dust Suppression. Rock Products, 75:137, May 1972.

14. Vandegrift, A. E., L. J. Shannon, P. G. Gorman, E. W. Lawless, E. E. Sallee, and M. Reichel. Particulate Pollutant Systems Study, Volume III: Handbook of Emission Properties. Contract CPA-22-69-104, U.S. Environmental Protection Agency, Durham, North Carolina, May 1971. 607 pp.

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APPENDIX A

LITERATURE SURVEY

A study was made to predict and analyze those parameters affecting dust emissions from the seven handling operations in crushed sandstone, quartz, and quartzite processing:

- drilling and blasting operations
- transport operations
- conveying operations
- unloading operations
- open storage
- loading operations
- crushing/grinding/sizing operations

Parameters analyzed fell into two major classifications: 1) those dependent on the material and 2) those dependent on the operation. As could be expected, parameters dependent on the operation are as varied as the operations themselves. Material-dependent parameters, however, are generally the same for all operations. These are: 1) moisture content, 2) density, and 3) "dustiness index," which will be defined as the mass of respirable dust adhering to 2.2 kg of material. The "dustiness index" is used to determine differences in emissions from different materials undergoing the same operation.

Density, on the other hand, delineates differences in particle size distribution between different samples of the same material.

DRILLING AND BLASTING OPERATIONS

The following factors influence the dust emissions from drilling operations:

1) number of bits
2) sharpness of the bits
3) speed of the bits
4) depth of bit penetration
5) experience of the machine operator

The literature search did not yield any quantitative data nor indicate a relationship between the emission factor and the aforementioned factors. A qualitative relationship might possibly resemble:

$$E_d \propto \frac{(1)(3)}{(2)(4)(5)} \qquad \text{(A-1)}$$

where the numbers in parentheses represent functions of the respective variables shown above.

Of all the unit operations, blasting has been studied least from the point of view of dust emissions. The literature search yielded a potential list of factors influencing emissions: 1) frequency of blasting, 2) bulk moisture content of the rock, 3) particle size distribution, 4) type and amount of explosive, and 5) hole size.

Some studies have been conducted on the magnitude of gaseous emissions of nitrogen oxides (NO_x) and carbon monoxide (CO) from blasting. Stoichiometric ratios of ammonium nitrate-fuel oil (ANFO) mixtures (5.5% fuel oil) should result in no emissions of NO_x and CO. Theoretically, more fuel oil results in no NO_x and more CO than carbon dioxide (CO_2), and less fuel oil results in no CO and more NO_x than nitrogen (N_2). Experimental investigations by the U.S. Bureau of Mines (23) show that 4% fuel oil results in 1.3 m^3 (at standard conditions) of NO_x per kg of ANFO and 1.3 m^3 of CO per kg of ANFO, while 6% fuel oil results in 0.32 m^3 of NO_x per kg of ANFO and 1.8 m^3 of CO per kg of ANFO. The maximum emission factor figures have been used for the severity calculations.

TRANSPORT OPERATIONS

Transport operations are discussed in detail in another assessment document (22).

CONVEYING OPERATIONS

Dust emissions from conveying operations come from windblown dust during open conveying and conveyor discharge.

Emissions from conveyor discharge and parameters affecting these emissions were evaluated by Cheng (24). The material tested was freshly mined coal, cut during a dry operation and placed in plastic bags to maintain its natural surface moisture of about 0.8% as measured by a Soiltest Speedy Moisture Tester. Cheng found the following relationship:

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(23) Chaiken, R. F., E. B. Cook, and T. C. Ruhe. Toxic Fumes from Explosives. Ammonium Nitrate-Fuel Oil Mixtures. Bureau of Mines RI-7867 (PB 233 496), U.S. Department of the Interior, Washington, D.C., May 1974. 29 pp.

(24) Cheng, L. Formation of Airborne-Respirable Dust at Belt Conveyor Transfer Points. American Industrial Hygiene Association Journal, 34(12):540-546, 1973.

$$R = 8.50 \times 10^5 \left(\frac{A \bar{\rho}_c \sqrt{2gH_f}}{2m\ b\ U_b} \right)^{1.16} \qquad \text{(A-2)}$$

where R = specific formation of airborne respirable dust, g
$\bar{A}$ = cross-sectional area of the falling granules, cm^2
ρ_c = material density of the coal, g/cm^3
g = gravitational acceleration = 980 cm/s^2
H_f = height of fall, cm
m = belt load, g/cm^2
b = width of the conveyor belt, cm
U_b = linear speed of the conveyor belt, cm/s

Cheng concluded the following:

- About 10% of the adhering respirable dust becomes airborne by the impact of dropping.
- Reduction of the height of material fall reduces the formation of airborne respirable dust.
- For heavy belt loads (coal bed thickness much greater than mean lump size), an increase in the thickness of the coal bed reduces the specific formation of airborne respirable dust.

UNLOADING OPERATIONS

Emissions from unloading operations result from dropping materials from conveying machinery onto storage piles. An EPA study (25) found an emission factor, E, for unloading operations, based on milligrams of suspended dust particles less than 30 μm in diameter per kilogram of aggregate unloaded, to be represented by the relationship:

$$E_u = \frac{20 \text{ mg of particulate}}{\text{kg of aggregate}} \qquad \text{(A-3)}$$

This emission factor was based on high-volume sampling at a sand and gravel plant in the Cincinnati area. E_u was believed to be dependent on the surface moisture of the material, estimated by the Precipitation-Evaporation (P-E) Index.

For an analysis of other factors affecting emissions from unloading operations, see Section 3 "Conveying Operations." Although

(25) Cowherd, C. Development of Emission Factor for Fugitive Dust Sources. EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 172 pp.

the relationships derived for emissions from conveyor discharge are based on coal conveyance, only a correction factor for the relative dustiness of the material handled need be applied to make the equation applicable to all conveying and unloading operations.

OPEN STORAGE

Emissions due to open storage have been discussed in detail in previous documents (22, 25, 26).

LOADING OPERATIONS

Emissions from loading operations occur in the transfer of material from storage to transporting vehicles. For aggregates, this transfer is accomplished by power shovels or front-end loaders scooping the material from open storage piles and dumping it into transporting vehicles, usually trucks. Dust arises from the scooping and dropping processes.

Emissions from dropping are determined by many of the same parameters that determine dust formation from conveyor discharge, although there are definite dissimilarities in mode of discharge between conveyor belts and power shovels. Dust emissions should be determined by:

1) Height of material fall
2) Quantity of material dumped
3) Density of material
4) Rate at which material is dumped
5) Moisture content of material
6) "Dustiness index" of material

An equation determining the amount of respirable dust (R) formed by power shovel discharge, based on an equation for conveyor discharge, should be of the form:

$$R \propto \frac{(1)(3)(6)}{(2)(4)(5)} \qquad \text{(A-4)}$$

where a number in parentheses represents a function of its respective parameter, as listed above.

Dust emissions from scooping operations are more difficult to define, since no information even remotely relevant was available. However, the following factors are believed to play a large part in determining emissions from this source:

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(26) Blackwood, T. R., T. F. Boyle, T. L. Peltier, E. C. Eimutis, and D. L. Zanders. Fugitive Dust from Mining Operations. Contract 68-02-1320, Task 6, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1975. p. 34.

7) Density of material
8) Moisture content of material
9) "Dustiness index" of material
10) Degree of storage pile disturbance rendered by the scooping machinery

Although there is no basis for determining a relationship between these variables and respirable dust formation (4), a qualitative relationship might possibly resemble

$$R \propto \frac{(7)(9)(10)}{(8)} \qquad \text{(A-5)}$$

where the number in parentheses represents a function of the respective variable shown above.

Although not applicable to the determination of R, an EPA study (25) found an emission factor, which can be expressed as milligrams of dust less than 30 μm in diameter emitted per kilogram of material loaded, for loading crushed limestone at an asphalt plant in Kansas City to be:

$$E_1 = \frac{25 \text{ mg of dust}}{\text{kg of material loaded}} \qquad \text{(A-6)}$$

E_1 was believed to vary with the P-E Index of the area considered.

CRUSHING/GRINDING/SCREENING OPERATIONS

Emissions from crushing, grinding, and screening (sizing) operations result from respirable dust formation during size reduction and crusher or screen discharge.

The factors affecting discharge emissions are the same as those for conveyor and power shovel discharge (see "Conveying Operations," and "Loading Operations" sections).

Dust emissions from size reduction are judged to be influenced by:

1) "Dustiness index" of material
2) Moisture content of material
3) Degree of particle-size reduction
4) Rate of material flow through size reducer

A qualitative expression for respirable dust formation (R) is believed to be:

$$R \propto \frac{(1)(3)}{(2)(4)} \qquad \text{(A-7)}$$

where each number in parentheses is some function of the respective parameter listed above.

If atmospheric dispersion of the respirable dust formed is to occur, an induced air flow must be present. For most crushers, which operate at a relatively low speed, air flow is induced only during discharge. (See "Conveying Operations" for a quantitative evaluation of air flow induced by discharge.)

High-speed pulverizers create air flow during both size reduction and discharge. Air flow induced by high-speed size reduction has been found to be inversely proportional to the rate of material flow through the size reducer (27).

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(27) Andresen, W. V. Industrial Hygiene Design in Raw Materials Handling Systems. American Industrial Hygiene Association Journal, 23(6):509-513, 1962.

APPENDIX B

EMISSIONS DATA--SAMPLING AND COMPUTATIONS

SAMPLING SITE DESCRIPTION

The purpose of the sampling conducted was to obtain data, on emissions from specific unit operations, presently lacking in the literature. Sampling was therefore limited in scope to provide an insight into the magnitude of emissions generation by various unit operations within the crushed sandstone, quartz, and quartzite (SQQ) industry.

A crushed quartzite plant was chosen for sampling since quartzite represents the average in the metamorphic scale between sandstone and quartz formation. In this manner, a more representative free silica content, the initial pollutant of primary concern, would be encountered. The site sampled contained three separate areas of operation; quarry, pit, and processing plant.

Quarry

At the quarry drilling is conducted to implant charges of ANFO to loosen the quartzite from the rock strate. An average of 8 to 9 holes are drilled once a month for 8 hours. A rough average of 7,716 metric tons/month of quartzite is then blasted. The blasted material is loaded by shovel onto 5.4-metric-ton trucks. The trucks then transport this material over unpaved roads to a pit area.

Pit

In the pit area, trucks dump and unload quartzite into a dump station. The aggregate is then conveyed to a wash tower for removal of clay and other foreign matter. In addition, the material is classified into three sizes: 1) 19 mm to 38 mm, 2) 6 mm to 19 mm, and 3) less than 6 mm. The classified and washed material is loaded through one of three hoppers to 8.2- or 22.7-metric-ton trucks for shipment to the processing plant or placement in stockpiles. As it is required by the processing plant, quartzite is loaded on trucks from storage at the pit by front-end loaders. The trucks transfer the material over unpaved roads to the processing plant. Only those unpaved roads located within the plant boundary are considered from an emissions standpoint.

Processing Plant

The plant utilizes quartzite in the production of bricks. Quartzite transferred to the plant is either placed in storage or dumped into a receiving hopper. Material in storage is placed in the hopper by a front-end loader. The aggregate is then conveyed to grinding (crushing) mills. These units exhaust through bag-type filters to the atmosphere. However, emissions from SQQ plants are studied from an uncontrolled perspective. The crushing units operate an average of 8 hr/day, 3 days/wk throughout the year. They handle 363 metric tons/month. Further operations at the processing plant are concerned with the manufacture of bricks and are not included within this source category.

The operation times and rates determined for the plant sampled are used in determining the emission factors for this plant. However, these data are also applicable to the representative plant, since the ratio of the operating times and rates is assumed constant. For example, if the amount of material blasted at the representative plant is greater, then the emission rate will increase proportionally. The operating times and rates for the source sampled are presented in Table B-1.

TABLE B-1. CRUSHED SANDSTONE, QUARTZ, AND QUARTZITE OPERATING CHARACTERISTICS AT SAMPLED PLANT

Emission source	Operating time	Operating rate
Drilling	$\frac{8 \text{ hr}}{\text{drilling}}$	$\frac{7{,}716 \text{ metric tons}}{\text{drilling}}$
Blasting	-[a]	$\frac{7{,}716 \text{ metric tons}}{\text{blast}}$
Truck loading	$\frac{0.02 \text{ hr}}{\text{truck}}$	$\frac{\text{truck}}{5.4 \text{ metric tons}}$
Truck unloading	$\frac{0.01 \text{ hr}}{\text{truck}}$	$\frac{\text{truck}}{5.4 \text{ metric tons}}$
Transport	$\frac{0.019 \text{ hr}}{\text{truck}}$	$\frac{\text{truck}}{22.4 \text{ metric tons}}$
Washing and screening	-[b]	$\frac{57 \text{ metric tons}}{\text{hr}}$
Conveying	-[b]	$\frac{67 \text{ metric tons}}{\text{hr}}$
Crushing	-[b]	$\frac{10 \text{ metric tons}}{\text{hr}}$
Stockpiles	Continuous	Continuous

[a]Finite release. [b]Included in operating rate.

SAMPLING PROCEDURES

Samplers

General Metal Works[a] high-volume samplers were positioned around an entire area, as shown in Figure B-1.

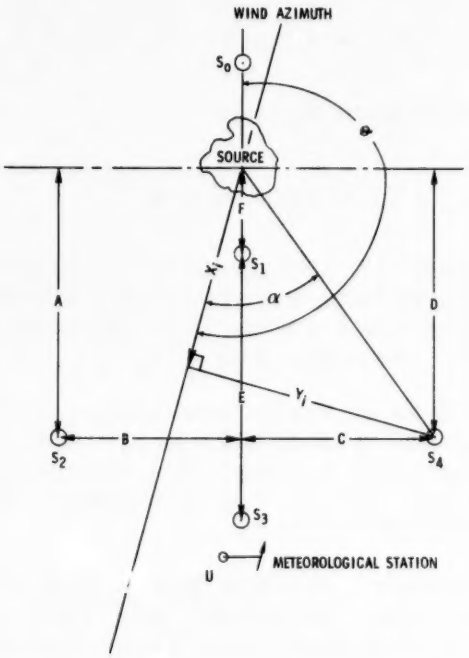

Figure B-1. Sampling arrangement.

For this arrangement, the origin was defined at the source and all all remaining points in the usual Cartesian coordinate system. The angle of mean wind direction was θ. The downwind distance of any point y_i perpendicular to the wind direction centerline was computed in the following manner:

$$m_1 = \tan \theta \qquad \text{(B-1)}$$

and for point S_i with coordinates x_i, y_i,

$$m_2 = \frac{y_i}{x_i} \qquad \text{(B-2)}$$

[a]General Metals Works, Inc., 8368 Bridgetown Road, Cleveland, Ohio 45002.

The angle α was found from

$$\alpha = \arctan \frac{m_1 - m_2}{1 + m_1 \cdot m_2} \qquad \text{(B-3)}$$

The lateral distance Y_i is:

$$Y_i = (\sin \alpha) \sqrt{x_i^2 + y_i^2} \qquad \text{(B-4)}$$

and the downwind distance X_i is:

$$X_i = (\cos \alpha) \sqrt{x_i^2 + y_i^2} \qquad \text{(B-5)}$$

These values are used in appropriate dispersion models. The sampling time for high-volume samplers was about 4 hours. Five different samplers were used to monitor emissions in the entire area at positions S_0, S_1, S_2, S_3, and S_4.

A GCA[a] respirable dust monitor was used to obtain downwind concentrations of respirable and total particulates from unit operations (28). The sampling time for the GCA instrument was about 4 minutes and hence only one unit was necessary to monitor at all the positions (not simultaneously).

The high-volume samplers collect particles less than 100 μm in size, while the GCA unit collects less than 10-μm particles with a cyclone separator and less than 50-μm particles without a cyclone separator.

Models

Open source sampling uses diffusion models in reverse. Normal use is to predict concentrations surrounding a point source of known strength. Several concentration readings are taken to calculate the source strength of an open source.

Models applicable to the sampling arrangement and source characteristics are chosen and utilized for each source of emissions. Three models are used in this study. The first represents emissions from front-end loading and runs 1 and 2 performed on the entire plant. This is the point source model (9) where:

[a]GCA Corporation, GCA/Technology Division, Bedford, Massachusetts.

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(28) Lilienfeld, P., and J. Dulchinos. Portable Instantaneous Mass Monitor for Coal Mine Dust. American Industrial Hygiene Association Journal, 33(3):136, 1972.

$$\chi\ (x,\ y,\ z;\ H) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \cdot \cdot$$

$$\cdot \cdot \cdot \left\{\exp\left[-\frac{1}{2}\left(\frac{z - H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z + H}{\sigma_z}\right)^2\right]\right\} \qquad \text{(B-6)}$$

The notation used to depict the concentration is χ (x, y, z; H). H, the height of the plume centerline from the ground level when it becomes essentially level, is the sum of the physical stack height, h, and the plume rise, ΔH. The following assumptions are made: the plume spread has a Gaussian distribution in both the horizontal and vertical planes, with standard deviations of plume concentration distribution in the horizontal and vertical of σ_y and σ_z, respectively; the mean wind speed affecting the plume is u; the uniform emission rate of pollutants is Q; and total reflection of the plume takes place at the earth's surface; i.e., there is no deposition or reaction at the surface. Any consistent set of units may be used. The most common is χ in g/m^3, Q in g/s, u in m/s, and σ_y, σ_z, H, x, y, and z in meters. The concentration χ is a mean over the same time interval as the time interval for which the σ's and u are representative. The values of both σ_y and σ_z are evaluated in terms of the downwind distance, x, and stability class. Stability classes are determined conveniently by graphical methods, Figure B-2. Continuous functions are then used to calculate values for σ_y and σ_z, from Tables B-2 and B-3, given the downwind distance, x (29). In open source sampling, the sampler is maintained in the center of the plume at a constant distance; the plume has no effective height (H equals 0); and the concentrations are calculated at ground level. Equation B-6 thus reduces to (9):

$$\chi\ (x,\ 0,\ 0;\ 0) = \frac{Q}{\pi\sigma_y\sigma_z u} \qquad \text{(B-7)}$$

The second model is used to describe emissions from transport on unpaved roads. In this equation, instantaneous puff concentrations are described by (30):

$$\psi = \left(\frac{2}{\pi}\right)^{\frac{1}{2}} \frac{Q_d}{\sigma_{zi} u} \qquad \text{(B-8)}$$

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(29) Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions of the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment, 6(11):859-863, 1972.

(30) Gifford, F. A., Jr. An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Chapter 3, D. A. Slade, ed. Publication No. TID-24190, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, Tennessee, July 1968. pp. 65-116.

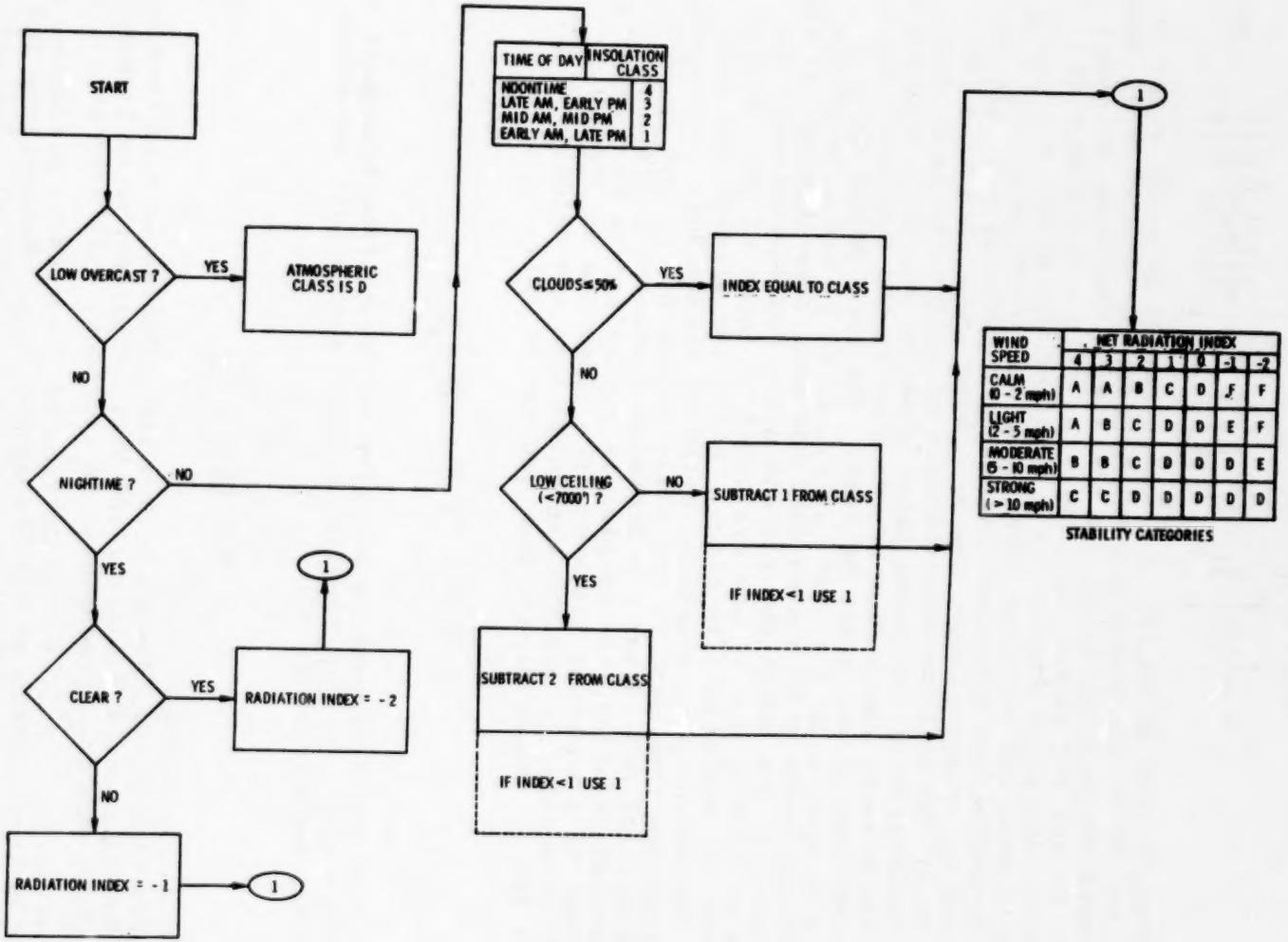

Figure B-2. Flow chart of atmospheric stability class determination.

TABLE B-2. VALUES OF a FOR THE COMPUTATION OF σ_y[a] (30)

Stability class	a
A	0.3658
B	0.2751
C	0.2089
D	0.1471
E	0.1046
F	0.0722

[a]For the equation

$$\sigma_y = ax^b$$

where x = downwind distance
b = 0.9031

TABLE B-3. VALUES OF THE CONSTANTS USED TO ESTIMATE VERTICAL DISPERSION[a] (30)

Usable range, m	Stability class	Coefficient		
		c_1	d_1	f_1
>1,000	A	0.00024	2.094	-9.6
	B	0.055	1.098	2.0
	C	0.113	0.911	0.0
	D	1.26	0.516	-13
	E	6.73	0.305	-34
	F	18.05	0.18	-48.6
		c_2	d_2	f_2
100 to 1,000	A	0.0015	1.941	9.27
	B	0.028	1.149	3.3
	C	0.113	0.911	0.0
	D	0.222	0.725	-1.7
	E	0.211	0.678	-1.3
	F	0.086	0.74	-0.35
		c_3	d_3	f_3
<100	A	0.192	0.936	0
	B	0.156	0.922	0
	C	0.116	0.905	0
	D	0.079	0.881	0
	E	0.063	0.871	0
	F	0.053	0.814	0

[a]For the equation

$$\sigma_z = cx^d + f$$

where ψ = dose, g-s/m^3

Q_D = line source emissions per length of line, g/m

σ_{zI} = instantaneous vertical dispersion parameter, m

u = mean wind speed, m/s

For neutral stability:

$$\sigma_{zI} = 0.15\ x_c^{0.7} \qquad \text{(B-9)}$$

where x_c = crosswind distance from the line source, m

Equation B-8 is a line source diffusion model and is used to find the mass emissions per length of road. The value of the dose, ψ, is determined by multiplying the concentration by the actual sampling time.

The third model is used in computing total dose from a finite release in blasting. This is calculated from Equation B-10 (9):

$$D_T = \frac{Q_T}{\sigma_y \sigma_z u}\, e^{-\frac{1}{2}\left(\frac{y}{\sigma y}\right)^2} \qquad \text{(B-10)}$$

The parameters of Equation B-10 use the same units as Equation B-6, except Q_T is the total release in grams from the source, and D_T is the total dose, g-s/m^3. Again, the dose is the product of the concentration and sampling time. Equation B-10 is therefore termed a dose model.

Data Collection

Each variable for each of these models was determined in the field at meteorological stations. High-volume sampling used a stationary meteorology station. Wind speeds were averaged every minute with a mean recorded for each 15-minute interval. The mean wind speed was calculated from the average of the 15-minute recordings over the entire run. The samplers were therefore maintained within the plume during sampling. The wind direction variation was less than ±0.79 rad from the centerline during the samplings.

The concentration at sampler S_0 was subtracted from the concentrations at S_1, S_2, S_3, and S_4 to yield concentrations due to the source emissions. Mass emission rate was then calculated as an average of the calculations done for N sampler readings using the appropriate dispersion equation.

The respirable dust monitor was mounted on the portable meteorological station shown in Figure B-3. For each monitor concentration reading, displayed by direct digital readout, the mean wind

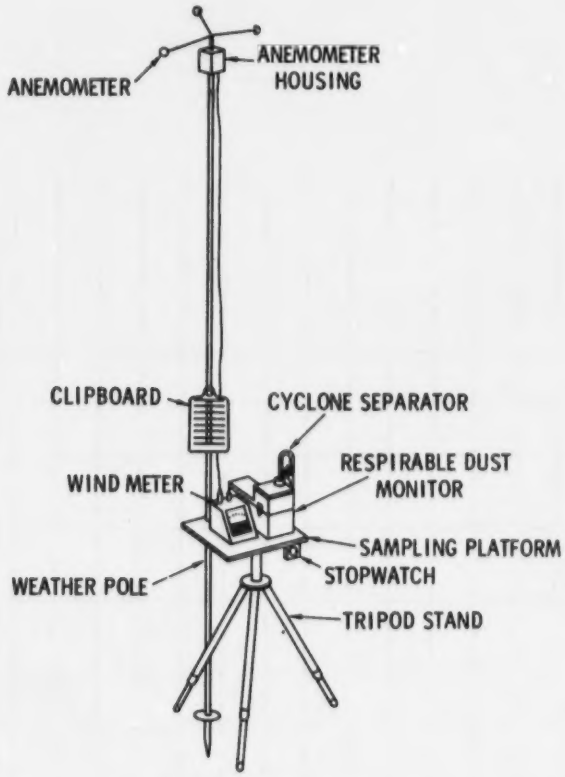

Figure B-3. Sampling apparatus.

speed was determined by averaging 15-s readings (a stopwatch was used) of the wind meter. This meter is connected to the anemometer which sits atop a 3.05-m pole. Distance x was approximated by manually pacing over the rough terrain.

All these data were recorded for each sampling run on the form shown in Figure B-4 while in the field. The time of day and atmospheric stability (determined following Figure B-2) were recorded periodically on the bottom of the form.

The terms used on the field data form (Figure B-4) are explained in Table B-4.

Any factors that might have affected concentration or emission rate were mentioned in the column labeled "Comments." When this form was completed, the data were programmed into a computer, and the emission rate, Q, was calculated in accordance with the model specified in the column labeled "M."

MODEL: POINT = 1
LINE = 2
DOSE = 3

SOURCE TYPE _____

DATE _____
BY _____

UNIT OPERATION	WIND SPEED, MPH	DISTANCE, FT. X	Y	Z	TIME, MIN.	READ., mg/m^3	CONC. μg/m^3	R/T	BGD, μg/m^3	Δ, μg/m^3	Q, g	S'	M	COMMENTS

TIME OF DAY ____ ____ ____ ____ ____
ATM. STABILITY ____ ____ ____ ____ ____

TOTAL SAMPLING TIME	MULTIPLY READING BY
4 MINUTES	1
8 MINUTES	0.46
16 MINUTES	0.23
20 MINUTES	0.184
30 MINUTES	0.122
37 MINUTES	0.1

Figure B-4. Field data form.

TABLE B-4. EXPLANATION OF FIELD DATA FORM TERMS

Term	Meaning
Read., mg/m^3	Concentration reading
Conc., $\mu g/m^3$	Converted concentration for sampling times >4 minutes (lower right-hand corner)
R/T	R = respirable reading, T = total mass reading
BGD, $\mu g/m^3$	Background concentration
Δ, $\mu g/m^3$	The difference between the converted concentration and the background
Q, g or g/s	Calculated emission rate
S'	Stability for the time of day the unit operation was sampled
M	The model used referenced as 1, 2, or 3 (point, line, or dose, respectively)

EMISSION LEVELS

Particulates

The parameters of Equations B-6, B-8, and B-10 were measured in the field in order to determine the emission rates (Q) per unit operation from the dispersion models. These data are recorded on the form in Figure B-4 and printed out via computer in Table B-5. The value of Q is automatically calculated from the dispersion model (M) specified in the input (Figure B-4). Measurements were performed on only those sources lacking published data. By sampling the site described in this appendix and referring to other studies, the following emission factors were determined.

Drilling--
Particulate emissions from drilling holes for loosening quartzite from the strata were assumed equivalent to those levels reported in a crushed stone operation (7). The levels for respirable and total particulates from drilling (E_{dr} and E_{dt}) are 0.005 and 0.05 g/metric ton, respectively. Respirable particulates account for 10% of the total particulates emitted in wet drilling.

Blasting--
The blasting operation was sampled at the quartzite site. The dose model (Equation B-10) yielded emission quantities of 4,366 g and 44.2 g of total and respirable particulates, respectively.

This finite release occurred during the blasting of an approximated average of 7,716 metric tons (Table B-1). Therefore the

TABLE B-5. SAMPLING DATA AND RESULTS

Unit operation	Preliminary sampling data and results[a]								
	u	x	y	z	Time	χ	Q	Units	S'
Run 1--S_4	4.6	226	0.0	0.0	210	171.6	$1.077E^{-1}$	(g/s)	B
Run 2--S_1	5.0	150	0.0	0.0	145	148.9	$4.806E^{-2}$	(g/s)	B
Run 2	5.0	150	0.0	0.0	4	10.0	$7.472E^{-4}$	(g/s)	D
Front end loading[b]	1.0	50	0.0	0.0	4	100.0	$8.692E^{-4}$	(g/s)	B
Front end loading	5.0	50	0.0	0.0	8	4.6	$4.842E^{-5}$	(g/s)	D
Washing plant--over	12.0	250	0.0	0.0	7	271.0	$1.209E^{-1}$	(g/s)	D
Unpaved road	5.0	20	0.0	0.0	4	110.0	$1.197E^{-4}$	(g/m-s)	D
Unpaved road	8.0	25	0.0	0.0	8	73.6	$1.559E^{-4}$	(g/m-s)	D
Unpaved road	5.0	30	0.0	0.0	4	160.0	$5.380E^{-4}$	(g/m-s)	B
Unpaved road	5.0	35	0.0	0.0	8	41.4	$1.605E^{-4}$	(g/m-s)	B
Blasting[b]	3.0	300	40.0	0.0	8	101.2	4.418E1	g	B
Blasting	3.0	300	40.0	0.0	16	5,000.0	4.366E3	g	B

[a] u = wind speed, mph; x, y, z = downwind, lateral, and vertical distance, ft; time = min; χ = concentration, μg/m^3; Q = emission rate in units printed out; S' = stability class.

[b] Respirable particulates (≤7 μm geometric mean diameter particles).

emission factors for total particulates and respirable particulates from blasting (E_{bt} and E_{br}) are:

$$E_{bt} = \frac{4{,}366 \text{ g}}{7{,}716 \text{ metric tons}} = \frac{0.56 \text{ g}}{\text{metric ton}}$$

$$E_{br} = \frac{0.003 \text{ g}}{\text{metric ton}}$$

Respirable particulates are 1% of the total mass particulate emitted from blasting.

Truck Loading--

Trucks at the quartzite plant sampled are loaded by shovels and front-end loaders. Front-end loading was sampled, and two concentration values were produced. Using the point source model (Equation B-6), emission rates of 4.8×10^{-5} and 8.7×10^{-4} g/s for respirable and total particulates were computed. It takes an assumed 1.2 min (0.02 hr) to load a 5.4-metric-ton truck; therefore, total particulate and respirable particulate emission factors from loading (E_{lt} and E_{lr}, respectively) are:

$$E_{lt} = \left(\frac{8.7 \times 10^{-4} \text{ g}}{\text{s}}\right)\left(\frac{0.002 \text{ hr}}{\text{truck}}\right)\left(\frac{\text{truck}}{5.4 \text{ metric tons}}\right)\left(\frac{3{,}600 \text{ s}}{\text{hr}}\right) = \frac{0.012 \text{ g}}{\text{metric ton}}$$

$$E_{lr} = \frac{0.0006 \text{ g}}{\text{metric ton}}$$

Respirable particulates constitute 5% of the emitted total mass particulate from loading operations.

Transport on Unpaved Roads--
Unpaved road emissions at the quartzite plant were sampled with emission rates in g/m-s computed from the line source model (Equation B-8). The average emission rate of total particulates was 2.4×10^{-4} g/m-s. Three truck sizes were used: 5.4-metric-ton, 8.2-metric-ton, and 22.7-metric-ton capacity. The latter two were used for transport of finished material; the smaller truck was used for raw (unwashed) quartzite. The raw quartzite truck capacity plus the average of the finished material truck capacities, 22.4 metric tons, represent the average amount of material associated with transport on unpaved roads. The effective sampling time is an average of 320 s (0.088 hr) for the four readings after the initial and final beta count times of the respirable dust monitor are subtracted (28). Therefore, the total particulate emission factor from transport (E_{tt}) is:

$$E_{tt} = \left(\frac{2.4 \times 10^{-4}\ g}{m\text{-}s}\right)\left(\frac{2 \times 600\ m}{truck}\right)\left(\frac{truck}{22.4\ metric\ tons}\right)(0.088\ hr)\left(\frac{3{,}600\ s}{hr}\right)$$

$$= \frac{4.1}{metric\ ton}$$

The emission factor for respirable particulates from transport (E_{tr}) is calculated from the assumption that 18% of the total particulates are respirable, based on crushed stone sampling (7). Therefore:

$$E_{tr} = \frac{0.74}{metric\ ton}$$

Washing and Screening--
One sample was taken of emissions from the washing plant area. The point source model (Equation B-6) produced an emission rate of 1.2×10^{-1} g/s. The washing unit processes an average of 57 metric tons/hr of quartzite. The total particulate emission factor from washing and screening (E_{wst}) is thus:

$$E_{wst} = \left(\frac{1.2 \times 10^{-1}\ g}{s}\right)\left(\frac{hr}{57\ metric\ tons}\right)\left(\frac{3{,}600\ s}{hr}\right) = \frac{7.6\ g}{metric\ ton}$$

Respirable particulates are assumed to be 11% of the total mass level based on the average percent level from all crushed stone operations (7). Therefore, the washing and screening respirable emission factor (E_{wsr}) is:

$$E_{wsr} = \frac{0.84\ g}{metric\ ton}$$

Truck Unloading (E_u), Conveying (E_c), Crushing (E_{cr}), and Stockpiles (E_s)--
Emission factors for these unit operations are all taken from crushed stone data, except that for stockpiles which is taken from

a study of wind erosion of coal stockpiles. These emission factors are presented below with the respirable percent in parentheses.

E_{ut} = 0.13 g/metric ton (7)

E_{ur} = 0.05 g/metric ton (42%)(7)

E_{ct} = 1.73 g/metric ton (7)

E_{cr} = 0.11 g/metric ton (7%)(7)

E_{crt} = 13.4 g/metric ton (7)

E_{crr} = 1.34 g/metric ton (10%)(7)

E_{st} = 6.4 g/metric ton-yr (26)

E_{sr} = 0.4 g/metric ton-yr (6.3%)(26)

The emission factors for crushing (E_{crt} and E_{crr}) were based on sampling of primary crushing at a crushed stone operation. The overall emission factors for the entire plant (assuming all operations occur at once) are 3.6 g/metric ton (respirable) and 34.7 g/metric ton.

Free Silica, Trace Elements, and Fibers

The particulates emitted from the crushed quartzite quarry operation were analyzed for free silica, trace elements, and fibers. The free silica analysis is presented in Table B-6. The mean content of free silica is 17%. Free silica is defined as crystalline silica, and the most common form of crystalline silica is quartz. Quartz is also the chief source of free silica in rock formations. Quartzite is a metamorphic form of sandstone and therein contains more nonperiodic, random silicon dioxide (SiO_2) arrangements, termed amorphic. Amorphorus silica is not classified as free silica (31). The particulate collected was therefore not 100% free silica since it was quartzite rock dust. The 17% free silica content is applied to each unit operation in determining emission factors applicable to free silica emissions.

Fibers are defined as particles greater than 5 μm in length with a length-to-width ratio greater than or equal to 3 (32). The fiber analysis of emissions from the crushers is presented below. The emission factor for fibers is computed from the point source

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(31) Criteria for a Recommended Standard: Occupational Exposure to Crystalline Silica. NIOSH 75-120, U.S. Department of Health, Education, and Welfare, Rockville, Maryland, 1974. 121 pp.

(32) Criteria for a Recommended Standard: Occupational Exposure to Asbestos. HSM 72-10267, U.S. Department of Health, Education, and Welfare, Rockville, Maryland, 1972. 89 pp. plus appendices.

TABLE B-6. FREE SILICA ANALYSIS OF EMISSIONS FROM CRUSHED QUARTZITE QUARRY

Sample	Free silica, %
1	8.0
2	17.0
3	24.8
4	17.2
Mean value	17
Standard deviation	±6.9
95% Confidence interval	17 ± 11

Field area = 0.005 mm^2

Count = 100 fields

Average count per field = 18

Ground level concentrations (x = 46 m, y = 0, and z = 0 m from the source) = 0.02 fiber/cm^3

E_{fb} = Emission factor for fibers = 1,360 fibers/metric ton

model (Equation B-6) using high-volume samplers. Elemental analyses of quartzite particulate emissions from the crushed quartzite quarry area are shown in Table B-7. These analyses indicate silicon levels consistent with the free silica levels detected in the previous sample (see Table B-6). The high level of lead detected in sample 2 (73.3%, Table B-7) was studied by determining, through the "Student t" test, the mean of the four lead samples, 1.02% ± 1.53 standard deviation. The confidence limit for these four samples is 1.02% ± 2.43 at the 95% level. Values greater than 3.4% therefore are beyond the upper confidence level, and the probability of the greater than 3.3% value indicating the true mean is less than 5%, assuming a normal distribution. The average percentage of the elements in Table B-7 are used in computing each emission factor from the particular data.

Nitrogen Oxides and Carbon Monoxide

Emission factors for nitrogen oxides and carbon monoxide emitted from the blasting operation (E_{bNO_x} and E_{bCO}, respectively) are based on computations performed on experimental investigations by the Bureau of Mines (23). These values are as follows:

$$E_{bNO_x} = 2.85 \text{ g/metric ton}$$

$$E_{bCO} = 1.68 \text{ g/metric ton}$$

TABLE B-7. ELEMENTAL ANALYSES OF QUARTZITE PARTICULATE EMISSIONS FROM CRUSHERS

Element	Weight %				
	Sample 1	Sample 2	Sample 3	Sample 4	Average
Silicon	5.8 to 17.5	3.3 to 10	6.62 to 19.86	5.32 to 16	10.55[a]
Calcium	1.2	1.7 to 3.3	3.31 to 6.62	2.66 to 5.32	3.16[a]
Copper	0.6	1 to 2.0	0.4	1.06	0.89[a]
Iron	0.5	0.7	3.31 to 6.62	1.06 to 2.66	2.00[a]
Aluminum	0.4	0.7	1.32	0.43	0.71
Lead	0.4	>3.3[b]	0.2	0.16	0.25
Sodium	0.2	0.2	0.53	0.48	0.35
Magnesium	0.2	0.1	0.13	0.16	0.15
Tin	0.02	0.02	0.01	0.02	0.02
Titanium	0.04	0.03	0.07	0.05	0.05
Manganese	0.04	0.03	0.03	0.04	0.04
Nickel	0.02	0.007	Negligible	<0.005	0.008[c,d]
Chromium	0.01	0.02	0.01	0.01	0.01
Silver	0.006	<0.003	<0.005	<0.005	0.005[d]
Zinc	Negligible	0.20	Negligible	1.06	0.32[c]
Vanadium	Negligible	<0.003	<0.005	<0.005	0.003[c,d]

[a] For samples 1 through 4, average values of ranges were used to compute the overall average.

[b] Value rejected due to use of "t" test discussed in text.

[c] Negligible value = 0.

[d] < value equated to maximum.

EMISSION BURDENS AND GROWTH FACTOR

Emission Burdens

State or national emission burdens for each pollutant refer to the ratios, expressed as percent, of the annual mass of a particular pollutant emitted from a source to the total mass of that pollutant emitted in a state or nationally. These are referred to as the state and national emission burdens. These levels are computed for the entire source, not on a unit operation basis. Emission burdens are computed only for criteria pollutants (33): total particulates, sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), and hydrocarbons (HC). Using the emission factors for these pollutants, the mass levels listed in Table B-8 (34) are obtained. Mass emissions per state are the product of the emission factor and production per state (Table 3).

(33) Air Quality Data - 1972 Annual Statistics. EPA-450/2-74-001, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 1974. 137 pp.

(34) 1972 National Emissions Report. EPA-450/2-74-012, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 422 pp.

TABLE B-8. MASS EMISSIONS AND EMISSION BURDENS FROM SANDSTONE, QUARTZ, AND QUARTZITE SOURCES

State	Mass emissions: Total particulates, SQQ (metric tons/yr)	Total particulates, All sources (34) (metric tons/yr)	Total particulates, Percent	Carbon monoxide, SQQ (metric tons/yr)	Carbon monoxide, All sources (34) (metric tons/yr)	Carbon monoxide, Percent	Nitrogen oxides, SQQ (metric tons/yr)	Nitrogen oxides, All sources (34) (metric tons/yr)	Nitrogen oxides, Percent
Alabama	1.8	1,178,643	<0.001	0.09	1,885,657	<0.001	0.15	397,068	<0.001
Arizona	17.5	72,685	0.024	0.85	815,454	<0.001	1.4	123,871	0.001
Arkansas	179.7	137,817	0.13	8.7	843,204	0.001	15	168,989	0.009
California	167.5	1,006,452	0.017	8.1	8,237,667	<0.001	14	1,663,139	0.001
Colorado	6.8	201,166	0.003	0.33	875,781	<0.001	0.56	147,496	<0.001
Georgia	2.6	404,574	0.001	0.13	2,036,010	<0.001	0.21	369,817	<0.001
Missouri	7.0	202,435	0.003	0.34	1,854,901	<0.001	0.57	448,300	<0.001
Montana	12.2	272,688	0.004	0.59	611,061	<0.001	1.0	148,405	0.001
New Mexico	3.5	102,785	0.003	0.17	504,249	<0.001	0.29	199,181	<0.001
New York	22.5	160,044	0.014	1.1	4,881,922	<0.001	1.8	572,451	<0.001
North Carolina	2.0	481,017	<0.001	0.1	1,734,398	<0.001	0.17	412,599	<0.001
Ohio	29	1,766,056	0.002	1.4	5,205,719	<0.001	2.4	1,101,470	<0.001
Oregon	5.8	169,449	0.003	0.28	929,247	<0.001	0.48	135,748	<0.001
Pennsylvania	113.2	1,810,598	0.006	5.5	3,729,830	<0.001	9.3	3,017,345	<0.001
South Dakota	29.6	52,336	0.057	1.4	387,356	<0.001	2.4	49,490	0.005
Texas	33.3	549,399	0.006	1.6	6,897,748	<0.001	2.7	1,303,801	<0.001
Utah	4.8	71,692	0.007	0.23	402,527	<0.001	0.39	80,998	<0.001
Vermont	1.6	14,587	0.011	0.08	150,510	<0.001	0.13	24,286	0.001
Virginia	23.2	477,494	0.005	1.1	1,548,031	<0.001	1.9	329,308	0.001
Washington	28.1	161,934	0.017	1.4	1,659,117	<0.001	2.3	187,923	0.001
West Virginia	32	213,715	0.015	1.6	494,214	<0.001	2.6	229,598	0.001
Wisconsin	36	411,558	0.009	1.7	1,582,869	<0.001	2.9	408,525	0.001
Other states[a]	86	3,410,426	0.003	4.2	13,400,994	<0.001	7.1	4,534,944	<0.001
NATIONAL TOTAL	931	17,872,000	0.005	40.9	96,868,000	<0.001	69.4	22,258,000	<0.001

[a]Includes Connecticut, Idaho, Kansas, Kentucky, Maryland, Michigan, Minnesota, Nevada, New Hampshire, Oklahoma, Tennessee, and Wyoming.

Growth Factor

The growth factor is the ratio of mass emissions at the present time to the level expected at the end of 5 years. These levels are computed from the product of present and future production rates and the overall emission factor for each criteria pollutant emitted from the source. The emission levels in Table B-8 are computed on the basis of 1972 production rates. These emission levels are converted to present levels from the data presented in Table 6 (in the text). The emission level in 1982, 5 years from 1977, is also computed from the production data in Table 6.

The 1972 level of mass emissions of total particulates from SQQ sources is 741.4 metric tons/yr. The present 1977 level is based on the production quantity presented in Table 6. Emissions of 1,043 metric tons of total particulates will be generated in 1977.

The levels in 1982 are expected to yield 1,287 metric tons of total particulates. The ratio of these two values yields the growth factor (GF):

$$GF = \frac{1{,}287 \text{ metric tons}}{1{,}043 \text{ metric tons}} = 1.23$$

APPENDIX C

SOURCE SEVERITY AND AFFECTED POPULATION

SOURCE SEVERITIES

Source severity is a variable computed to indicate the hazard potential of emissions from a source, representative of an industry. Severity is equivalent to a time-averaged maximum downwind concentration of a pollutant at a representative distance divided by a hazard factor computed for that pollutant. Mathematical models are employed to describe the dispersion of pollutants in the atmosphere. For open sources, such as quarries, the model employs the concentration of a pollutant occurring at ground level. This concentration may occur only once a year and be considered a worst case condition. The hazard factor is derived from ambient air quality criteria and adjusted threshold limit values (8).

Concentrations of pollutants downwind of a source are computed for class C atmospheric (Tables B-2 and B-3) stability using the point source model (Equation B-6) at an average wind speed. The instantaneous downwind concentration at distance x is then corrected to a time-averaged maximum (9). The hazard factor is a corrected TLV from an 8- to a 24-hr exposure, with a safety factor of 100 applied. For criteria pollutants, the national ambient air quality standards are used (33). For free silica, the TLV equals 10 mg/m^3 divided by (2 + % respirable quartz) (6). Inserting these factors, the severity equations reduce to the form shown in Table C-1. In these equations, Q is the emission rate in g/s, and x is the downwind distance. Severities are calculated for representative sources at the representative downwind distance. The value of Q is a product of the emission factor for a particular operation (which is determined using other dispersion models, Appendix B) and the representative production rate. For stockpiles, Q is the product of the emission factor and annual production for the representative plants. The source severities are computed using the Table C-1 relationships.

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(35) Blackwood, T. R., and R. A. Wachter. Source Assessment: Coal Storage Piles. Contract 68-02-1874, U.S. Environmental Protection Agency, Cincinnati, Ohio, July 1977. 96 pp.

TABLE C-1. SEVERITY EQUATIONS (35)

Pollutant	Severity equation	
Particulate	$S = \frac{4{,}020\ Q}{x^{1.81}}$	(C-1)
NO_x	$S = \frac{22{,}200\ Q}{x^{1.90}}$	(C-2)
CO	$S = \frac{44.8\ Q}{x^{1.81}}$	(C-3)
Hydrocarbons	$S = \frac{93.40\ Q}{x^{1.81}}$	(C-4)
SO_x	$S = \frac{2{,}870\ Q}{x^{1.81}}$	(C-5)
Other	$S = \frac{316\ Q}{(TLV)(x^{1.81})}$	(C-6)

The severities for particulates, free silica, fibers, NO_x, and CO are presented in Table C-2.

TABLE C-2. SOURCE SEVERITY VALUES FOR THE REPRESENTATIVE SANDSTONE, QUARTZ, AND QUARTZITE SOURCES

Unit operation	Source severity				
	Respirable particulates	Free silica particulates	Fibers	NO_x	CO
Drilling	0.00005	0.001	[a]	[b]	[b]
Blasting	0.00003	0.0007	[a]	0.09	0.0002
Truck loading	0.00001	0.0002	[a]	[b]	[b]
Transport on unpaved roads	0.007	0.19	[a]	[b]	[b]
Washing and screening	0.008	0.21	[a]	[b]	[b]
Truck unloading	0.0005	0.013	[a]	[b]	[b]
Conveying	0.001	0.03	[a]	[b]	[b]
Crushing	0.013	0.34	2.2×10^{-7}	[b]	[b]
Stockpiles	0.0003	0.008	[a]	[b]	[b]
TOTAL	0.034	0.91	2.2×10^{-7}	0.09	0.0002

[a] No determination made. [b] Not applicable.

Severities for trace elements are determined by using the average percent of the trace elements detected within particulates. These percentages are applied to the total emission factors for respirable particulates from the entire source. The resulting severities are presented in Table C-3.

TABLE C-3. SOURCE SEVERITIES FOR TRACE ELEMENTS FROM THE REPRESENTATIVE CRUSHED SANDSTONE, QUARTZ, AND QUARTZITE SOURCE

Element	Severity	Element	Severity
Calcium	0.017[a]	Manganese	0.0002[b]
Copper	0.022	Nickel	0.00002[d]
Iron	0.01[c]	Titanium	0.00005[e]
Aluminum	0.0017[b]	Chromium	0.0005[b]
Lead	0.04[f]	Gold	0.00001[b]
Sodium	0.004[g]	Zinc	0.0007
Magnesium	0.0004	Vanadium	0.0001
Tin	0.0002		

[a] TLV based on calcium oxide, 5 mg/m^3.

[b] TLV based on nuisance particulates, 10 mg/m^3.

[c] TLV based on iron oxide fume, 5 mg/m^3.

[d] TLV based on proposed level, titanium dioxide, 20 mg/m^3.

[e] TLV based on chromium salts, 0.5 mg/m^3.

[f] TLV based on sodium hydroxide, 2 mg/m^3.

[g] TLV based on magnesium oxide fume, 10 mg/m^3.

Severity for fibers emitted from SQQ operations was determined for the crushers sampled. The crusher represents the highest severity for respirable particulates from a unit operation. At a TLV of 5 fibers/cm^3 (6), the severity is computed as 2.2×10^{-7}. Fibers from other unit operations were not analyzed.

AFFECTED POPULATION

Affected population refers to the number of persons exposed to a ground level concentration, χ, for which $\chi/F>0.1$. Therefore, the product of the representative population density and the area where $\chi/F>0.1$ will yield an affected population level. The affected area is established by setting S equal to 0.1 in the equation (Table C-1) and determining the downwind distance at which this occurs. This distance is used to compute the affected area as the area of the $\chi/F = 0.1$ circle minus the area within the source boundaries.

There is no affected population for respirable particulates where S is greater than or equal to 0.1 since the total severity from the representative source is 0.027. Severities are also less than 0.1 for NO_x, CO, fiber, and trace element emissions. However, for free silica particulates, the severity at the representative distance of 410 m is 0.91. The distance at which

$\bar{\chi}/F$ equals 0.1 is determined by using the emission rate for free silica particulates in Equation C-7:

$$0.1 = \frac{316\ Q}{(TLV)\,(x^{1.81})} \qquad \text{(C-7)}$$

where Q = emission rate, $(0.17)\left(\frac{2.9\ g}{\text{metric ton}}\right)\left(\frac{0.126\ \text{metric ton}}{s}\right)$

TLV = threshold limit value, $\frac{10\ mg/m^3}{2}$ + 17%

x = unknown

Using these data, the value of x from Equation C-7 is 458 m. The affected area is thus located between 410 m and 458 m, where these distances are the radii of concentric circles. Therefore, the area affected is:

$$A_z = \pi(458\ m)^2 - \pi(410\ m)^2 = 130{,}825\ m^2$$

The affected population for free silica emissions based on the representative population density, 38.8 persons/km^2, is therefore:

$$A_{pfs} = (130{,}825\ m^2)\left(\frac{38.8\ \text{persons}}{km^2}\right)\left(\frac{km^2}{1 \times 10^6\ m^2}\right) = \text{five persons}$$

GLOSSARY

amorphous: Without stratification or other division; uncrystallized.

ANFO: Ammonium nitrate and fuel oil mixture used as an explosive.

atmospheric stability class: Coding used to represent the turbulent state of the atmosphere.

azimuth: Horizontal direction expressed as the angular distance between the direction of a fixed point (as the observer's heading) and the direction of the object.

chromite: Black mineral, $FeCr_2O_4$, with a metallic luster and uneven fracture; the chief ore of chromium.

confidence interval: Range over which the true mean of a population isexpected to lie at a specific level of confidence.

criteria pollutant: Pollutant for which ambient air quality standards have been established.

detrital: Relating to fragments or rocks produced by disintegration or wearing away.

dustiness index: Reference used in measuring the amount of dust settled where a material is dropped in an enclosed chamber.

emission burden: Ratio of the total annual emissions of a pollutant from a specific source to the total annual state or national emissions of that pollutant.

feldspar: Any of several crystalline minerals comprised mainly of aluminum silicates.

fibrosis: Abnormal increase in the amount of fibrous connective tissue in an organ or tissue.

field area: Microscopic area examined for fiber content.

free silica: Crystalline silica defined as silicon dioxide (SiO_2) arranged in a fixed pattern (as opposed to an amorphous arrangement).

garnet: Hard, glasslike silicate mineral of various colors.

granite: Very hard igneous rock, usually gray or pink, consisting chiefly of crystalline quartz, feldspar, and mica.

hazard factor: Measure of the toxicity of prolonged exposure to a pollutant.

igneous: Produced by the action of fire, formed by volcanic action or great heat.

limestone: Rock consisting mainly of calcium carbonate.

magnetite: Black, iron oxide (Fe_3O_4) which is an important iron ore.

metasomatic: Relating to metamorphism that involves important changes in the chemical composition and in the mineral composition and texture of rocks.

metamorphic: Changed in structure by pressure, heat, chemical action, etc.

processing plant: That portion of the source where the operation of crushing and size classification of stone occurs.

pulverizer: Crusher used to reduce stone size to powder or dust.

pyrite: Iron sulfite, FeS_2, a mineral occurring as a native ore.

quarry: Term used to refer to the mining and material transfer operations.

quartz: Crystalline silicon dioxide, SiO_2, occurring in abundance usually in a colorless, transparent form.

quartzite: Massive, hard, light-colored rock with a flinty sheen; it is a metamorphoses sandstone.

representative source: Source that has the mean emission parameters.

respirable particulates: Those particles with a geometric mean diameter of less than or equal to 7 μm.

rutile: Lustrous bark-colored mineral titanium dioxide, TiO_2, commonly found in prismatic crystals and usually containing iron.

rock: Stone in a mass.

sandstone: Common sedimenary rock consisting of sand grains, usually quartz, cemented together by silica, lime, etc.

sedimentary: Describes matter or mass deposited by wind or water.

severity: Hazard potential of a representative source defined as the ratio of time-averaged maximum concentration to the hazard factor.

silicosis: Chronic disease of the lungs caused by the continued inhalation of silica dust.

sizing screen: Mesh used to separate stone into various sizes.

stone: Hard, solid, nonmetallic mineral matter of which rock is composed.

threshold limit value: Concentration of an airborne contaminant to which workers may be exposed repeatedly, day after day, without adverse effect.

zircon: Silicate of zirconium, $ZrSiO_4$, occurring in tetragonal crystals.